Influence of initial planting density, geographic location, and species on juvenile wood formation in southern pine

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Abstract

The influence of initial planting density on the date of transition from juvenile to mature wood of loblolly and slash pine was estimated from wood specific gravity of growth increments at breast height. Results show that planting density does not significantly affect the age of transition from juvenile to mature wood but it does affect the diameter of the juvenile core. Slash pine planted at spacings of 6 by 6, 8 by 8, 10 by 10, and 15 by 15 feet in the Upper Coastal Plain of Georgia produced juvenile wood through 10 rings from the pith and loblolly pine planted at spacings of 6 by 6, 8 by 8, 10 by 10, and 12 by 12 feet in the Piedmont of South Carolina produced juvenile wood through 14 rings from the pith. Average diameter of the juvenile core at breast height ranged from 4.0 inches in slash pine planted at 6- by 6-foot spacing to 6.3 inches in trees planted at 15- by 15-foot spacing. In loblolly pine, the average juvenile core diameter ranged from 5.2 inches in trees planted at 6- by 6-foot spacing to 7.7 inches in trees planted at 12- by 12-foot spacing. In a separate but related phase of this study, we determined that the difference in the period of juvenility between slash and loblolly pine was not species-related, but rather due to geographic location. Plantations containing both slash and loblolly pine were sampled at five locations from the Central Piedmont in South Carolina south to the Gulf Coastal Plain in Florida. At all locations the period of juvenile wood formation was the same for both species. These data indicate that the length of juvenility is related to environmental factors associated with geographic location rather than to species differences. The length of the juvenile period of slash and loblolly pine in the Southeast decreased geographically from north to south. In loblolly and slash pine, the period of juvenile wood formation decreased from 14 years in the Piedmont to 6 years in the Gulf Coastal Plain.

Background

One-third of the South's pine timberlands currently consists of plantations. Wood supplies are now coming and will increasingly come from these plantations. Wood from young, fast-growing plantations has physical and mechanical properties that make it less desirable than wood from older, natural stands because plantation trees have more juvenile wood (3). Juvenile wood has lower specific gravity and shorter tracheids with thinner walls, larger fibril angles, and less alpha cellulose than mature wood (17). Building products containing juvenile wood are weaker (2,13,15) and more prone to warp, creating problems for manufacturers and consumers (14).

A radial cross-section of a pine stem contains three zones of wood (Fig. 1): 1) core or crown-formed wood — wood produced by immature cambium in the vigorous crown which has anatomical, chemical, and physical properties substantially different from mature wood; 2) transition wood—the zone in which wood properties are changing rapidly before reaching maturity; and 3) mature wood. In the spring, radial growth begins at the apex of the bole in the vigorous crown (18,19) resulting in a larger proportion of thin-walled earlywood tissue in the upper bole near or in the crown than in the lower bole. The transition to thick-walled latewood tissue occurs first near the base of the bole, farthest from the source of auxins, and proceeds upward as moisture stress increases and translocation of auxins down the bole decreases (8,19). As trees grow older and stands close, lower branches cease

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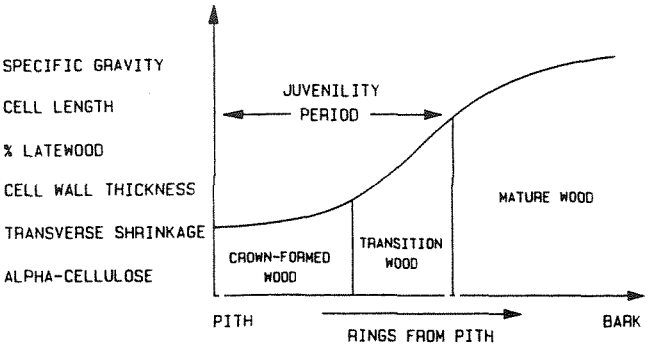


Figure 1. — Schematic diagram of radial change in wood properties with age from pith and the pattern of maturation.

to be vigorous, and the active crown region moves up the stem. Therefore, there is a core of crown-formed wood surrounded by a band of transition wood from the butt to the merchantable top of the tree (12,23). Both crown-formed wood and transition wood are commonly referred to as juvenile wood.

Researchers have found specific gravity and tracheid length of juvenile wood to be under moderate to strong genetic control (9,11,21,22). Loo and others also reported that the length of juvenility is genetically inherited. Genetic influence is implied when species such as loblolly (*Pinus taeda* L.) and slash pine (*P. ellioti Engelm.*) are compared. Based on the literature, loblolly has a juvenility period of 9 to 12 years (13,20) while slash has an average juvenility period of 6 to 8 years (8,16,21).

The size of the juvenile core in plantation trees is related to the rate of growth which, in turn, is influenced by initial planting density. Using growth and yield simulation, Martin (10) showed that the proportion of bole wood composed of juvenile wood is highly influenced by initial spacing. He reports that trees planted at 7 by 7 feet, thinned at age 16 and 27, and harvested at age 35 will have approximately the same average diameter at breast height as trees planted at 12 by 12 feet, not thinned, and harvested at age 35, but the former will have only 31 percent of their boles in juvenile wood compared to 51 percent for the unthinned 12 by 12 trees. Franklin (5) predicted that timber buyers will pay less for sawlogs from plantations than from natural or direct-seeded stands because of their high juvenile wood content.

The objectives of this study are to: 1) determine the effect of initial planting densities on the period of transition from juvenile to mature wood and the proportional volume of juvenile wood at breast height; 2) examine wood formation of planted slash and loblolly pine grown under the same environmental conditions to determine if species differences exist; and 3) examine how the length of juvenility varies with geographic location.

Annual rings can be classed as crown-formed, transition, or mature wood on the basis of cell structure and the proportions of earlywood and latewood tracheids. These factors determine or correlate with the average specific gravity of the ring. In this paper, specific gravity is used to separate juvenile and mature wood.

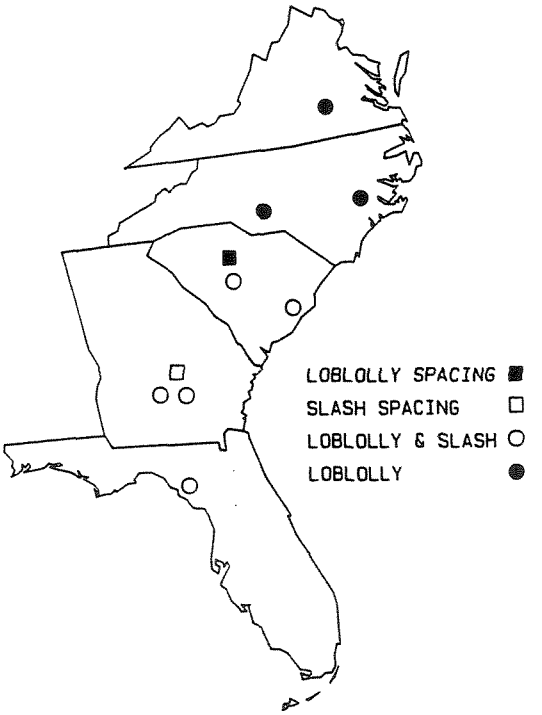


Figure 2. — Location of plantations sampled for evaluating the effect of initial planting density, geographic location, and species on juvenile wood formation of loblolly and slash pine.

Procedure

Field

To examine the effect of initial planting density on length of juvenility, plantations from two separate spacing studies were sampled. A slash pine study established in 1952 on the Holt Walton Experimental Forest on the Upper Coastal Plain of Georgia in Dooly County (7) and a loblolly pine study established in 1957 on the Calhoun Experimental Forest on the Piedmont of South Carolina in Union County (1,6) serve as the study material. The slash pine study has a randomized block design with two replications. Plots with spacings of 6 by 6, 8 by 8, 10 by 10, and 15 by 15 feet were sampled. Two 10-mm increment cores were removed at breast height from each of 15 randomly selected trees from each plot and replication. The loblolly pine spacing study has a randomized block design with four replications. Plots with spacings of 6 by 6, 8 by 8, 10 by 10, and 12 by 12 feet were sampled. Two increment cores were removed from each of 10 randomly selected trees from each plot and replication.

In a separate but related phase of this study, eight other plantations were sampled to examine length of juvenility associated with species and geographic location. Five of these plantations contained both loblolly and slash pine either interplanted or planted adjacent to each other at locations extending from the Piedmont of South Carolina to northwest Florida. Plantations sampled in North Carolina and Virginia contained only loblolly pine but were sampled to expand the range of our sample for examining the associated difference in juvenility with geographic location in this species. At all locations and for

each species, two 12-mm increment cores were removed at breast height from 30 randomly selected trees. Figure 2 shows the location of all plantations sampled. Means and ranges of physical dimension of sample trees are shown in Table 1.

Laboratory

In the laboratory, one increment core from each tree was separated into 2-year segments, starting from the pith and ending with the 20th ring. The unextracted specific gravity of each 2-year segment was determined based on green volume and ovendry weight. Specific gravity of the remainder of the increment core was also determined and included with the segments defined as mature wood. The second core from each tree was dried, glued into a slotted core holder, and surface-sanded. The width of earlywood and latewood of each ring was measured to the nearest 0.001 mm with a microscope and a digitizing stage at 65×.

Specific gravities of the juvenile wood and mature wood zones were determined by weighting segment specific gravity and the specific gravity of rings 21 to bark in proportion to their incremental basal area. The age at which transition from juvenile to mature wood occurred was estimated based on visual examination of plots of ring specific gravity over rings from pith. An analysis of variance and Duncan's Multiple-Range Test were performed to determine whether spacing significantly affected specific gravity of juvenile wood, mature wood, or the combined zones at the $p=0.05$ percent level. An analysis of variance and Duncan's Multiple-Range Test were also performed to determine if the specific gravity of loblolly and slash pine differ significantly when growing at the same location.

The loblolly and slash pines sampled from the two plantations in Dooly County, Georgia, were combined by species as a single location after analysis of the data showed no significant difference in the juvenility period or wood specific gravity.

Results

Graphic plots of average 2-year specific gravity data over rings from pith for each spacing show that slash pine in the Upper Coastal Plain (Fig. 3) produced juvenile wood for the first 10 rings for all spacings sampled. Wood produced in the 2-year segments after the 10th year has mature wood qualities. The diameter of the juvenile wood zone was significantly related to initial spacing and averaged 4.0 inches in trees spaced 6 by 6 feet, 4.6 inches in trees spaced 8 by 8 feet, 5.5 inches in trees spaced 10 by 10 feet, and 6.3 inches in trees spaced 15 by 15 feet.

Although the point of transition to mature wood is less clear, loblolly pine in the Piedmont (Fig. 4) has a longer and more gradual juvenile transition period up to and including the 14th ring, after which mature wood is produced. The diameter of the juvenile wood zone in lob-

TABLE 1. — *Means and range of sample tree measurements by study, location, and species.*

Species and location	Tree			DBH		Total height	
	Spacing	Sampled	Age	Average	Range	Average	Range
	(ft.)	(no.)	(yr.)	(in.)		(ft.)	
Effect of spacing							
South Carolina Piedmont							
Loblolly pine	6 by 6	40	30	8.0	6.0 to 11.0	68	55 to 80
	8 by 8	40	30	9.0	6.6 to 12.2	71	66 to 76
	10 by 10	40	30	9.7	7.0 to 11.7	71	65 to 80
	12 by 12	40	30	11.3	9.0 to 15.6	73	60 to 84
Georgia Coastal Plain							
Slash pine	6 by 6	30	35	7.3	5.9 to 9.2	60	50 to 65
	8 by 8	30	35	8.9	6.1 to 11.5	71	64 to 75
	10 by 10	30	35	10.7	8.0 to 13.0	74	68 to 81
	15 by 15	30	35	12.9	10.6 to 16.3	76	68 to 81
Species comparison							
South Carolina Piedmont							
Loblolly pine	8 by 8	30	27	9.5	7.8 to 11.9	70	66 to 74
Slash pine	8 by 8	30	27	9.8	7.6 to 11.7	69	60 to 74
South Carolina Coastal Plain							
Loblolly pine	8 by 8	30	31	10.1	8.5 to 11.7	69	62 to 75
Slash pine	8 by 8	30	31	10.3	8.3 to 12.3	73	68 to 78
Georgia Coastal Plain							
Loblolly pine	8 by 8	60	31	10.6	8.0 to 13.6	72	60 to 80
Slash pine	8 by 8	55	31	10.1	8.3 to 13.1	71	65 to 76
Florida Coastal Plain							
Loblolly pine	6 by 9	30	24	8.8	7.0 to 11.0	62	50 to 75
Slash pine	6 by 9	30	24	8.1	6.8 to 11.0	62	52 to 72
Effect of geographic location							
Virginia Piedmont							
Loblolly pine	6 by 10	30	29	9.7	7.8 to 12.1	62	54 to 67
North Carolina Piedmont							
Loblolly pine	6 by 10	30	28	9.4	8.1 to 12.5	66	60 to 70
North Carolina Coastal Plain							
Loblolly pine	6 by 10	30	26	9.8	7.2 to 12.5	65	52 to 72

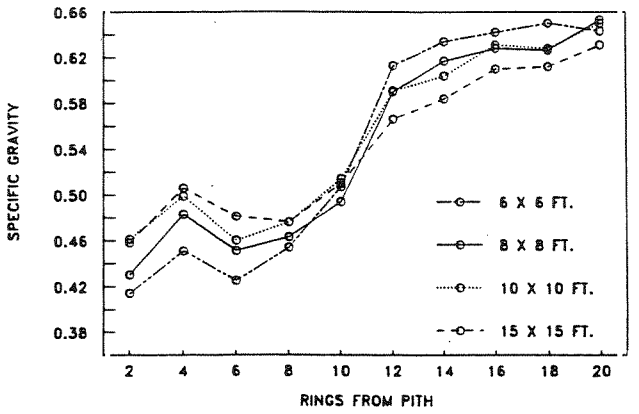


Figure 3. — Influence of spacing on wood specific gravity at breast height of slash pine planted in the Upper Coastal Plain of Georgia.

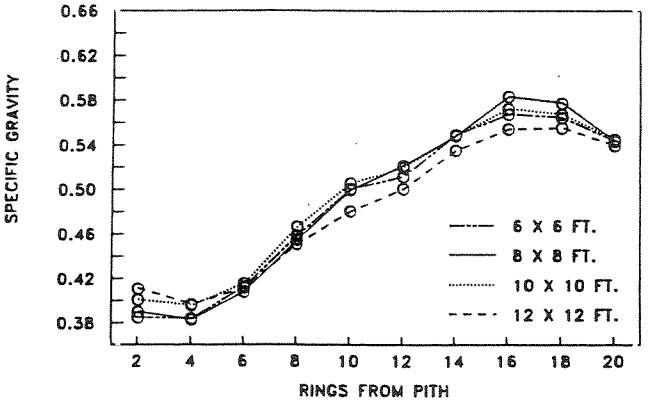


Figure 4. — Influence of spacing on wood specific gravity at breast height of loblolly pine planted in the Piedmont of South Carolina.

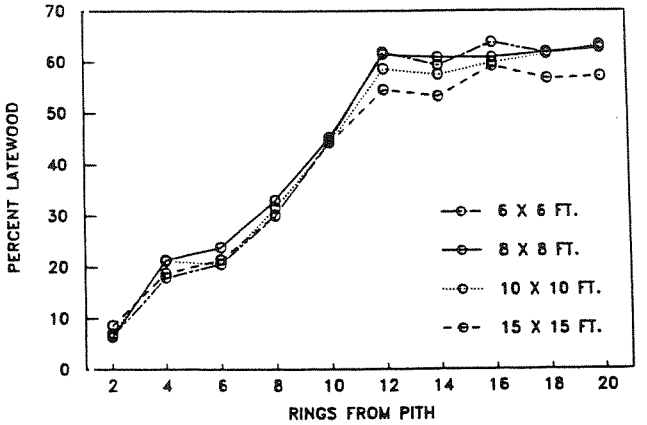


Figure 5. — Influence of spacing on percent latewood at breast height of slash pine planted in the Upper Coastal Plain of Georgia.

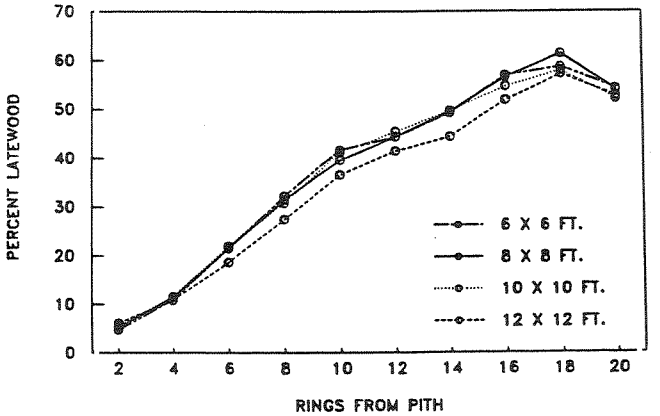


Figure 6. — Influence of spacing on percent latewood at breast height of loblolly pine planted in the Piedmont of South Carolina.

lolly pine averaged 5.2 inches in trees spaced 6 by 6 feet, 6.0 inches in trees spaced 8 by 8 feet, 6.6 inches in trees spaced 10 by 10 feet, and 7.7 inches in trees spaced 12 by 12 feet.

Spacing did influence wood specific gravity during plantation development. In the early years, before stand closure, trees at wider spacing on the average had higher wood specific gravity; after stand closure, the reverse was true. For example, the specific gravity of juvenile wood produced in the first eight rings from pith of slash pine was highest at wider spacing, but the trend reversed in the later development of the plantation (Fig. 3). A similar, but less pronounced, trend is found in loblolly pine (Fig. 4). A possible explanation for these trends is that young trees growing at wide spacings have less competition for site resources and thus produce more photosynthate and denser earlywood than trees at closer spacing. As the stands develop, specific gravity becomes more strongly influenced by the proportions of earlywood and latewood tissues produced. Wider-spaced trees tend to produce larger percentages of earlywood, thus, the trends reverse.

Spacing influenced both specific gravity and percent latewood of mature wood (Figs. 4 to 7). However, statistical analysis indicates that the only statistically significant difference occurred in slash pine mature wood specific gravity between the 6- by 6-foot and 15- by 15-foot spacings (Table 2). The persistent crowns of slash pine planted at 15- by 15-foot spacing and of loblolly pine planted at 12- by 12-foot spacing delayed the transition from earlywood to latewood during the growing season at the height levels sampled. Thus, trees at the wider spacing contained less latewood on a percentage basis and lower specific gravity.

Several studies in the literature indicate that the period of juvenility in slash and loblolly pine differ — loblolly pine between 9 and 12 years, and slash pine from 6 to 8 years (8,13,16). The results of our study show that the period of juvenility of slash and loblolly pine is less influenced by inherent species differences than by environmental differences associated with geographic location. When these species are grown in the same or neighboring plantations, they display the same juvenility pattern when measured by wood specific gravity changes.

Figure 7 shows specific gravity trends for the two species at four different locations ranging from the Piedmont of South Carolina to the Gulf Coastal Plain of Florida. At each location, the pattern of juvenility is similar for both species. In the Piedmont of South Carolina, both species produced juvenile wood for the first 14 rings from pith; for 10 years in the Coastal Plain of Georgia and South Carolina; and for 6 years in the Gulf Coastal Plain of Florida.

The analysis of variance showed that across locations there was no significant difference in juvenile wood, mature wood, or all wood weighted specific gravity between the two species. Across locations, combined juvenile and mature wood weighted specific gravity averaged 0.54 for slash pine and 0.53 for loblolly pine. Loblolly and slash pine specific gravity of all wood did not vary significantly when the two species were growing together on the Piedmont of South Carolina, or the Coastal Plain of South Carolina and Georgia (Table 3). However, in the Gulf Coastal Plain of Florida the specific gravity of juvenile wood and all wood combined of slash pine growing was significantly higher than that of loblolly pine. Loblolly at this location is outside its natural range.

The influence of geographic location on length of juvenility and wood specific gravity in loblolly and slash pines is shown in Figure 8. The plots of loblolly specific gravity over rings from pith show two groups of curves — one for the Piedmont locations and one for the Coastal Plain locations. As a group, loblolly pine sampled in the Coastal Plain produced juvenile wood for the first 6 to 10 rings while loblolly pine sampled in the Piedmont produced juvenile wood for about the first 10 to 14 rings.

The length of juvenility of slash pine also varied with geographic location (Fig. 8). In these data, the distinctions between locations are clearer. In Florida, slash pine produced juvenile wood for the first 6 years, for 10 to 12 years in the Coastal Plain of South Carolina and Georgia, and for 14 years in the Piedmont of South Carolina.

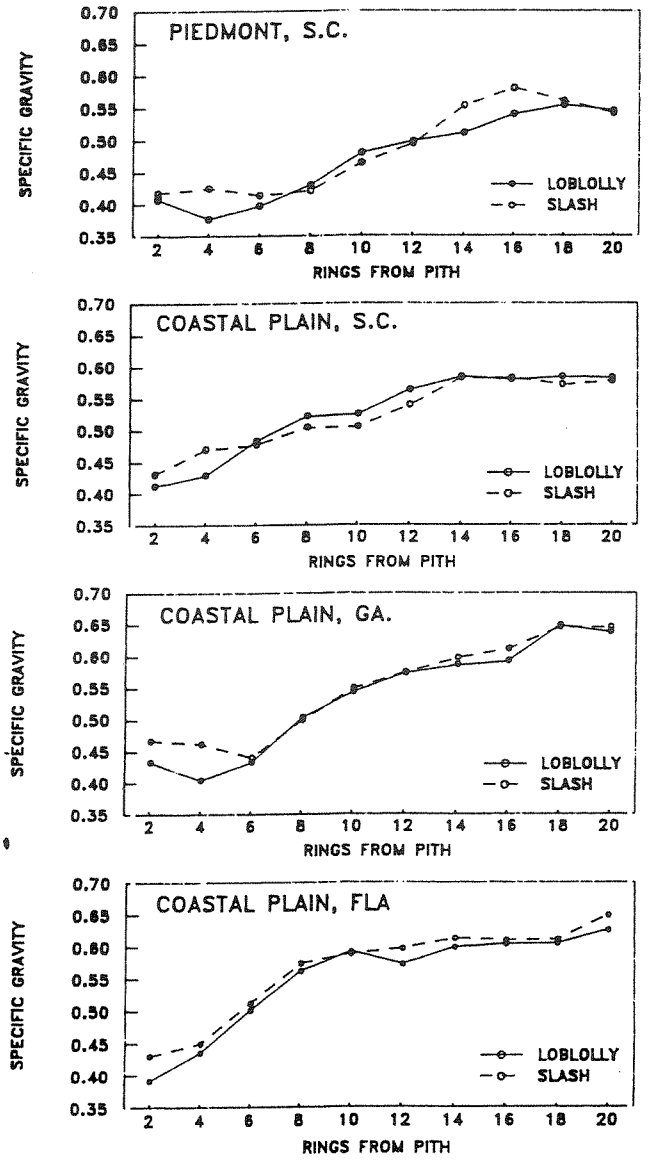


Figure 7. — Comparison of ring specific gravity for slash and loblolly pine growing together at four different locations.

TABLE 2. — *Effect of spacing on weighted specific gravity at breast height of loblolly and slash pine juvenile wood, mature wood, and all wood.*

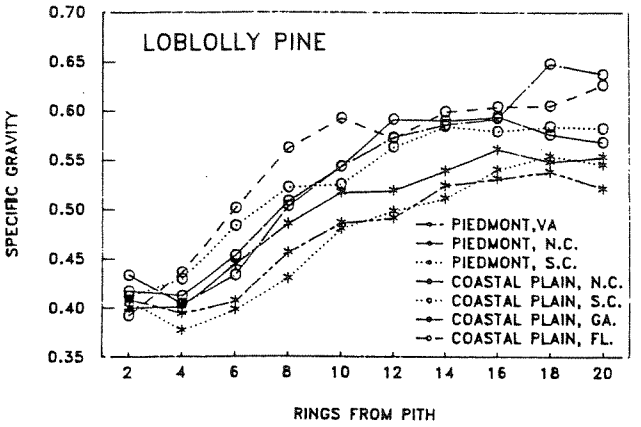
Spacing	Weighted specific gravity		
	Juvenile wood	Mature wood	All wood combined
(ft.)			
Piedmont loblolly pine			
6 by 6	.42 A[a]	.55 A	.46 A
8 by 8	.43 A	.56 A	.46 A
10 by 10	.44 A	.55 A	.47 A
12 by 12	.43 A	.54 A	.47 A
Upper Coastal Plain slash pine			
6 by 6	.45 A	.63 A	.51 A
8 by 8	.46 A	.62 A B	.52 A
10 by 10	.49 A	.62 A B	.54 A
15 by 15	.50 A	.60 B	.54 A

[a]Values with the same capital letter do not differ significantly at the 0.05 level according to Duncan's Multiple-Range Test.

TABLE 3. — *Comparison of length of juvenility and weighted wood specific gravity at breast height for loblolly and slash pine growing together at four locations in the Southeast.*

Species and location	Annual rings in juvenile zone	Weighted specific gravity		
		Juvenile wood	Mature wood	All wood combined
	(no.)			
South Carolina Piedmont				
Loblolly pine	14	.44 A[a]	.53 A	.47 A
Slash pine	14	.45 A	.54 A	.48 A
South Carolina Coastal Plain				
Loblolly pine	10	.49 A	.57 A	.55 A
Slash pine	10	.49 A	.57 A	.54 A
Georgia Coastal Plain				
Loblolly pine	10	.47 A	.60 A	.54 A
Slash pine	10	.49 A	.61 A	.55 A
Florida Coastal Plain				
Loblolly pine	6	.45 A	.58 A	.54 A
Slash	6	.47 B	.60 A	.57 B

[a]Within a location, values with the same capital letter do not vary significantly at the 0.05 level according to Duncan's Multiple-Range Test.



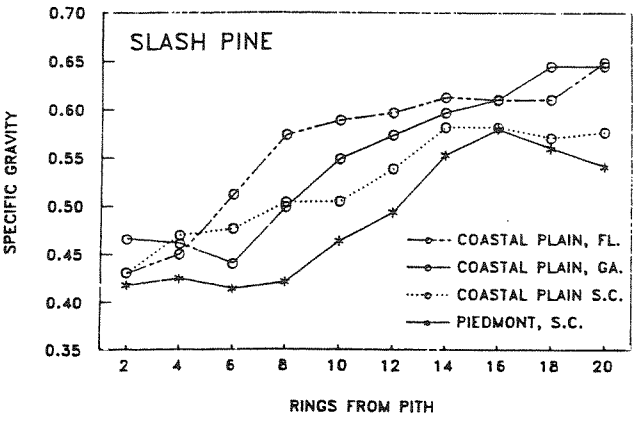


Figure 8. — Influence of geographic location on ring specific gravity and length of juvenility for loblolly and slash pine.

Three factors that can influence the proportion of tree basal area in juvenile wood at harvest are the: 1) age of the tree at harvest; 2) geographic location where the tree is growing; and 3) annual growth rate of the tree. The influence of tree age and geographic location on proportion of basal area in juvenile wood is illustrated in Figure 9. As a tree grows older the proportion of its basal area in juvenile wood decreases. After age 6, trees growing in the Gulf Coastal Plain have proportionally less basal area in juvenile wood at breast height than trees in the Atlantic Coastal Plain and the Piedmont.

Trees producing large annual increments after converting to mature wood will contain proportionally less basal area in juvenile wood than slower growing trees. This is illustrated with the slash pine spacing study data. Slash pine planted at the wider spacings grew faster and produced accumulatively more basal area than those planted at close spacing (Fig. 10). When comparing percent basal area in juvenile wood by spacing, the wider spaced, faster growing trees contained proportionally less basal area in juvenile wood (Fig. 11).

Summary and discussion

Results of this study show that the length of juvenility of slash and loblolly pine is not significantly influenced by initial planting density in unthinned plantations. Lob-

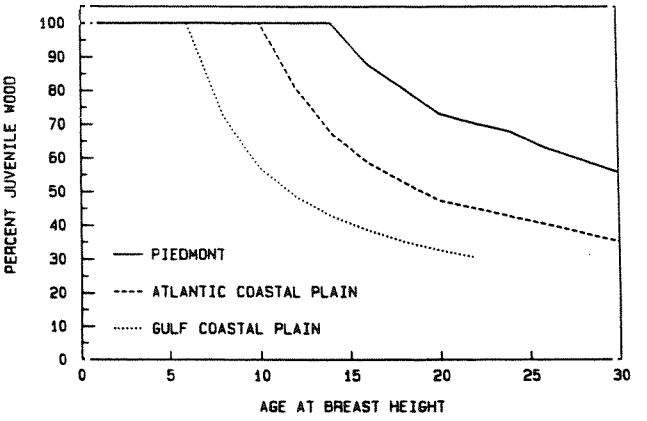


Figure 9. — Influence of geographic location and age at breast height on proportion of stem wood basal area in juvenile wood of loblolly pine.

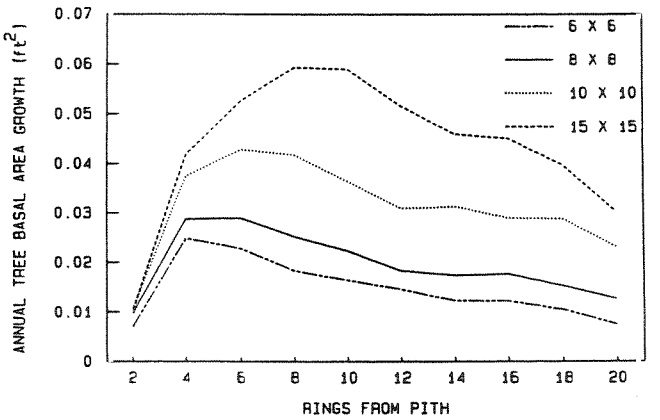


Figure 10. — Influence of spacing on average annual tree basal area growth at breast height of slash pine in the Upper Coastal Plain of Georgia.

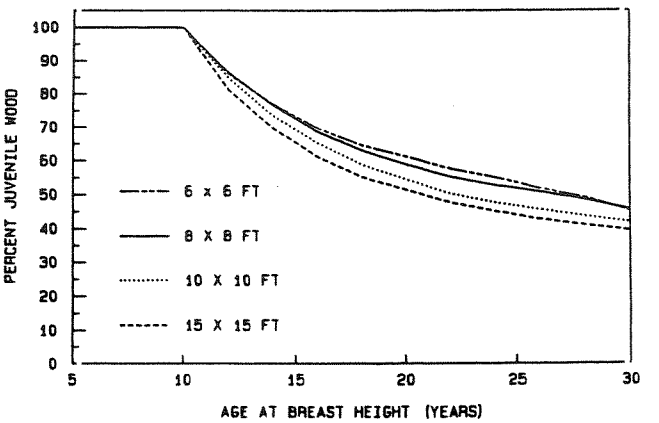


Figure 11. — Influence of spacing and age on proportion of tree basal area in juvenile wood of slash pine planted in the Upper Coastal Plain of Georgia.

lolly pine planting at spacings ranging from 6 by 6 feet to 12 by 12 feet, and slash pine planted at spacings ranging from 6 by 6 to 15 by 15 feet had similar juvenile/mature wood patterns among all spacing treatments. Only the mature wood specific gravity of slash pine planted at 15 by 15 feet was significantly lower than that of slash pine planted at 6 by 6 feet.

Loblolly and slash pine growing in the same or neighboring plantation at four geographic locations displayed the same juvenile patterns within locations. Reported differences in length of the juvenile period in these species is largely due to geographic differences, not species differences.

The length of the juvenile period of slash and loblolly pine in the Southeast decreased geographically from north to south. In loblolly and slash pine, the period of juvenile wood formation decreased from 14 years in the Piedmont to 6 years in the Gulf Coastal Plain.

The variation in length of juvenility with geographic location appears to be related to the climatic factors of temperature (length of growing season) and seasonal rainfall patterns. Zahner (19) hypothesized that when soil moisture is plentiful, cell division and maturation are rapid and there is severe competition for carbohydrates and auxins among newly formed cells. Under these conditions the cambium is better able to compete for these materials than maturing tracheids. Thus, the maturing tracheids die and become part of the earlywood. When soil moisture is scarce (moisture stress high), cambial activity is reduced, maturing tracheids can compete more successfully for available carbohydrates, wall thickening occurs, and latewood is produced.

Cregg et al. (4) observed that the transition from earlywood to latewood occurred 1 month earlier in a year of low rainfall and high spring evaporative demand than in a year of low evaporative demand and high rainfall. Thus, in the Coastal Plain the transition from earlywood to latewood probably occurs earlier than in the Piedmont because of the earlier arrival of hotter summer weather. However, the Coastal Plain continues to receive moisture sufficient for latewood production in the form of afternoon showers. In the Piedmont, however, moisture often becomes a limiting factor because of fewer afternoon showers and latewood production not only starts later in the growing season but also stops sooner because of severe moisture stress.

This study shows that although the juvenile period is not altered, planting density can be used to influence the size of the juvenile core by controlling radial growth. By planting close (8 by 8 ft.) and thinning after the trees are producing mature wood at the 1- or 1-1/2-log height level, resource managers can minimize the diameter of the juvenile core. Managers can also reduce the proportion of juvenile wood harvested by lengthening rotation age.

Literature cited

1. Balmer, W.E., E.G. Owens, and J.R. Jorgensen. 1975. Effects of various spacings on loblolly pine growth 15 years after planting. Res. Note SE-211. USDA Forest Serv. 7 pp.
2. Bendtsen, B.A. and J.F. Senft. 1986. Mechanical and anatomical properties in individual growth rings of plantation-grown eastern cottonwood and loblolly pine. Wood and Fiber Sci. 18(1):23-28.
3. _____. 1986. Quality impacts of the changing timber resource on solid wood products. *In:* Proc. Managing and Marketing the Changing Timber Resource. Forest Prod. Res. Soc., Madison, Wis. pp. 44-56.
4. Cregg, B.M., P.M. Dougherty, and T.C. Hennessey. 1988. Growth and wood quality of young loblolly pine trees in relation to stand density and climatic factors. Canadian J. of Forest Res. 18(7):851-858.
5. Franklin, E.C. 1987. Economics of forest management option influence on wood properties. Tappi. pp. 85-88.
6. Harms, W.R. and F.T. Lloyd. 1981. Stand structure and yield relationships in a 20-year-old loblolly pine spacing study. South. J. Appl. Forestry 5:162-166.
7. Jones, E.P., Jr. 1986. Slash pine plantation spacing study — age 30. *In:* Proc. 4th Biennial Southern Silvicultural Research Conference. D.R. Phillips, ed. Gen. Tech. Rept. SE-42. USDA Forest Serv., Southeastern Forest Expt. Sta. pp. 45-49.
8. Larson, P.R. 1969. Wood formation and the concept of wood quality. Bull. No. 74. School of Forestry, Yale Univ., New Haven, Conn. 54 pp.
9. Loo, J.A., C.G. Tauer, and R.W. McNew. 1985. Genetic variation in the time of transition from juvenile to mature wood in loblolly pine (*Pinus taeda* L.). Silvea Genetica 34(1):14-19.
10. Martin, J.W. 1984. Forest management practices that will influence product characteristics of the changing wood resource. *In:* Proc. Symposium on Utilization of the Changing Wood Resource in the Southern United States. R.C. Kellison, ed. North Carolina State Univ., Raleigh, N.C. pp. 115-123.
11. Matziris, D.I. and B.J. Zobel. 1973. Inheritance and correlations of juvenile characteristics in loblolly pine (*Pinus taeda* L.). Silvae Genetica 22(1/2):38-45.
12. Paul, B.H. 1957. Juvenile wood in conifers. Rept. No. 2094. USDA Forest Serv., Forest Prod. Lab., Madison, Wis. 8 pp.
13. Pearson, R.G. and R.C. Gilmore. 1980. Effect of fast growth rate on the mechanical properties of loblolly pine. Forest Prod. J. 30(5):47-54.
14. Quarles, S.L. and R.W. Erickson. 1987. Mechanism of ceiling-floor partition separation. Forest Prod. J. 37(9):33-39.
15. Senft, J.F., B.A. Bendtsen, and W.L. Galligan. 1985. Weak wood: fast-grown trees make problem lumber. J. of Forestry 83(8):477-484.
16. Taras, M.A. 1965. Some wood properties of slash pine (*Pinus elliotti* Engelm.) and their relationship to age and height — within the stem. Ph.D. diss. North Carolina State Univ., Raleigh, N.C.
17. Thomas, R.J. 1984. The characteristics of juvenile wood. *In:* Proc. Symposium on Utilization of the Changing Wood Resource in the Southern United States. R.C. Kellison, ed. North Carolina State Univ., Raleigh, N.C. pp. 40-52.
18. Wareing, P.F. 1958. The physiology of cambial activity. J. of Inst. of Wood Sci. (1):34-42.
19. Zahner, R. 1963. Internal moisture content stress and wood formation in conifers. Forest Prod. J. (6):240-247.
20. Zobel, B.J. and R.L. McElwee. 1958. Natural variation in wood specific gravity of loblolly pine, and an analysis of contributing factors. Tappi 41(4):158-161.
21. _____ and J.T. Talbert. 1984. Applied Forest Tree Improvement. John Wiley and Sons, N.Y. 505 pp.
22. _____, J.B. Jett, and R. Hutto. 1978. Improving wood density of short rotation southern pine. Tappi 61(3):41-44.
23. _____, C. Webb, and F. Henson. 1959. Core of juvenile wood of loblolly and slash pine trees. Tappi 42(5):345-355.